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Focus

Methods applied in studies of benthic marine debris

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Abstract

The ocean floor is one of the main accumulation sites of marine debris. The study of this kind of debris still lags behind that of shorelines. It is necessary to identify the methods used to evaluate this debris and how the results are presented and interpreted. From the available literature on benthic marine debris (26 studies), six sampling methods were registered: bottom trawl net, sonar, submersible, snorkeling, scuba diving and manta tow. The most frequent method used was bottom trawl net, followed by the three methods of diving. The majority of the debris was classified according to their former use and the results usually expressed as items per unity of area. To facilitate comparisons of the contamination levels among sites and regions some standardization requirements are suggested.

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1. Introduction

The large majority of marine debris are plastic, nylon, rubber, polystyrene and foam. These items can damage marine organisms, and can affect the economy of sectors like tourism. Residues caught in boats' propellers are also harmful for tourist, commercial and artisanal fishing and boats. Refrigeration systems of fishing boats may also be affected by the debris that may block their water inlet.

There are preferential places for the accumulation of marine debris, like estuaries, the shoreline and the ocean floor. The debris deposited on the ocean floor are called submerged benthic marine debris, or benthic marine debris. It is important to evaluate the status of the studies of benthic marine debris, beyond that commonly measured in estuaries and beaches, and to assess how these studies have been made and the degree to which they may be compared. Evaluation of the amount, types, distribution and sources of persistent debris are also required to develop efficient strategies for its control. The aim of the present short review is to identify the methods used for the qualification and quantification

of benthic marine debris, as well as to highlight the most common type of results presented in the literature. This is important for comparisons of the distribution of benthic marine debris over the world. It is believed that the majority of studies use bottom trawl net to collect samples of benthic marine debris and that the results are generally expressed as number of items per unit of area, and qualified in different categories according to their material.

2. Methods

Six different methods were recorded in the literature: bottom trawl net, sonar, submersible, snorkeling, scuba diving and manta tow. For each work, the location of the study was noted (western or eastern Atlantic, western or eastern Pacific, Mediterranean), the minimum and maximum depth, the area sampled, the unit used for expressing density, the total number of anthropogenic categories used to classify the debris and their sources (continental, marine or both). Also recorded was information about: the type of bottom (reef or not); temporal variation approach; number of items counted; weight of debris; dimensions (height, width and length) of debris; collection or not of debris from the area of study; whether the study of marine debris was a

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secondary part of another study; whether the impacts of the debris were assessed and; if the focus of the study was lost fishing gear.

3. Results

There were 26 studies between 1976 and 2007 (Table 1). Four studies employed two sampling methods. Galgani et al. (1996, 2000) used bottom trawl nets and submersible to evaluate the distribution of the marine debris off the French Mediterranean and European coasts. Dameron et al. (2007) used manta tow and snorkeling to survey the Northwestern Hawaiian Islands. Stevens et al. (2000) employed sidescan sonar to locate lost crab pots off Kodiak, Alaska, making use of submersible and ROV to confirm the remote observations. The majority of the studies utilized bottom trawl net (48.3%), followed by snorkeling (17.2%), scuba diving (13.8%), manta tow (10.3%), submersible (6.9%) and sonar (3.5%).

Eleven studies were conducted in the Pacific Ocean (two on the western coast and nine on the eastern coast, including the Hawaiian Islands), nine were done in the Atlantic Ocean (six on the western coast and three on the eastern coast) and seven studies had samples collected in the Mediterranean Sea (Fig. 1). One study (Galgani et al., 2000) was conducted along both the Atlantic and Mediterranean coasts of Europe.

Only six studies reported minimum and maximum depth and total area sampled (Table 1). Eight studies do not present any information about the range of water depth of the studied area and 14 do not give the total area sampled. It can be estimated that at least 7564 km² of the ocean's floor were sampled for benthic marine debris, between 0 and 4614 m.

Marine debris density was expressed as number of items per unit area: 100 m² (3 studies), 1000 m² (2), hectare (5) and per square kilometer (7 studies). Four articles showed the results as weight (kg) per unit area (100 m², 900 m² or km²). Number of items per linear distance (100 m or 1 km) was used to express the result in three studies and one created a nominal scale. Three articles showed the results in more than one unit of density, while six studies did not report density (Table 1).

The number of categories used to classify the benthic marine debris sampled is a choice of each author and depends on the objective of each study. Only one study

Table 1
A summary of the information of the studies about submerged benthic marine debris

Method	Location	Depth range	Area sampled	Unity of density	Reference
Bottom trawl net	Northeast Gulf of Alaska	_	_	_	Jewett (1976)
Bottom trawl net	Southeastern Bering Sea	_	_	_	Feder et al. (1978)
Bottom trawl net	Coast of Turkey	0–100 m	_	kg/km ²	Bingel et al. (1987)
Bottom trawl net	Eastern Bering Sea	7–675 m	33.1 km^2	n/km ²	June (1990)
Bottom trawl net	Bay of Biscay and Seine Bay, France	0–100 m	_	n/ha	Galgani et al. (1995a)
Bottom trawl net	Northwestern Mediterranean Sea	Up to 700 m	_	n/ha	Galgani et al. (1995b)
Bottom trawl net	Eastern Mediterranean	194.1–4614 m	_	_	Galil et al. (1995)
Bottom trawl net and	French Mediterranean coast	40–1630 m	Over	n/ha and n/100 m	Galgani et al. (1996)
submersible			4.016 km^2		
Bottom trawl net	Kodiak Island, Alaska	_	13.49 km^2	n/km ²	Hess et al. (1999)
Bottom trawl net	Echinadhes and Patras Gulfs, Greece	80–360 m	2.34 km^2	n/km ²	Stefatos et al. (1999)
Bottom trawl net and submersible	European coasts (Atlantic and Mediterranean)	Up to 2700 m	Over 7502 km ²	n/ha and n/km	Galgani et al. (2000)
Bottom trawl net	Southern California Bight	10-200 m	_	Nominal	Moore and Allen (2000)
Bottom trawl net	Rio de la Plata	_	_	n/km ²	Acha et al. (2003)
Bottom trawl net	East China Sea and South Sea of Korea	-	-	kg/km ²	Lee et al. (2006)
Snorkeling	Curação, West Indies	0–10 m	-	$n/100 \text{ m}^2$ and kg/ 100 m^2	Nagelkerken et al. (2001)
Snorkeling	Florida Keys National Marine Sanctuary	4–12 m	0.00804 km^2	n/100 m ²	Chiappone et al. (2002)
Snorkeling	Florida Keys National Marine Sanctuary	1–7 m	$0.0252~\mathrm{km^2}$	$n/100 \text{ m}^2$	Chiappone et al. (2004)
Snorkeling	Florida Keys National Marine Sanctuary	1–7 m	$0.0252~\mathrm{km^2}$	_	Chiappone et al. (2005)
Snorkeling and manta tow	Northwestern Hawaiian Islands	0–9 m	_	$kg/900 m^2$	Dameron et al. (2007)
Scuba diving	Kawau Island, New Zealand	Up to 10 m	_	_	Backhurst and Cole (2000)
Scuba diving	UK coastal waters	20–35 m	_	_	Revill and Dunlin (2003)
Scuba diving	Coastal areas of Greece	0–25 m	_	n/1000 m ²	Katsanevakis and Katsarou
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Scuba diving	Arvoredo Island, Brazil	Up to 25 m	0.0038175 km^2	$n/1000 \text{ m}^2$	Machado (2006)
Manta tow	Northwestern Hawaiian Islands	Up to 10 m	-	n/km ²	Donohue et al. (2001)
Manta tow	Northwestern Hawaiian Islands	_	4.65 km^2	n/km ²	Boland and Donohue (2003)
Sonar	Kodiak Island, Alaska	100–150 m	4.5 km ²	n/km ²	Stevens et al. (2000)



Fig. 1. Geographic distribution and quantifications of the available literature on submerged benthic marine debris. ○: one study; **⊙**: two studies (not registered); ⊙: three studies; **⊙**: four studies; **⊙**: five studies.

(Jewet, 1976) did not inform how the debris was classified. The greatest number of categories (24) was used by Backhurst and Cole (2000) at Kawau Island, northeastern New Zealand. Ribic et al. (1992) suggested three classifications, according to material, use or size. Considering that each study could have classified the benthic marine debris in more than one category, the classification by item use was most common, followed by classification by material. Size classification occurred three times.

The majority of the studies (16) identify the source of the benthic marine debris as being from marine activities (shipping lines, fishing). Only four articles pointed to the land as the source of debris (Stefatos et al., 1999; Galgani et al., 2000; Nagelkerken et al., 2001; Acha et al., 2003). Six suggested that the benthic marine debris had mixed sources (Bingel et al., 1987; Galgani et al., 1995b; Moore and Allen, 2000; Katsanevakis and Katsarou, 2004; Lee et al., 2006; Machado, 2006).

Collection of the debris occurred in most cases (80.8%), even though 46% of the studies of benthic marine debris were conducted as secondary result of other project objectives. Nine studies focused on lost fishing gear (Hess et al., 1999; Stevens et al., 2000; Donohue et al., 2001; Chiappone et al., 2002, 2004, 2005; Boland and Donohue, 2003; Revill and Dunlin, 2003; Dameron et al., 2007), while only six studies also evaluated the impact of the benthic marine debris on the environment (June, 1990; Stevens et al., 2000; Donohue et al., 2001; Chiappone et al., 2002, 2005; Revill and Dunlin, 2003).

4. Discussion

As expected, the most common method applied in the studies of benthic marine debris was bottom trawl net. This was the method used from 1976 to 1996, when another method (submersible) was introduced for the first time

(Galgani et al., 1996). The reason for the high use of trawling surveys might be that all studies up to 1996 (except June, 1990) were a consequence of another project which was researching fish stocks or benthic organisms. This pattern of sampling benthic marine debris as a secondary objective of the study occurred in 80% of the cases that used bottom trawl net. This is understandable, since it is widely known that information about benthic marine debris arises from the application of bottom survey techniques for other purposes. When a researcher is faced with marine debris contamination of his/her sample, a number of questions are immediately asked about the quality of the studied environment and therefore an interest in reporting or interpreting the data may generate a secondary work. Bottom trawl nets easily draw up items from the seabed across vast areas (Lee et al., 2006) and from substantial depths. However, this method also has limits, since it cannot be used on every type of bottom, such as reefs.

There could also be underestimations due to mesh size and the opening of the net used, and debris can be lost during the return of the net back to the ship. Another issue related to the mesh size and the opening of the net is that it was observed that their sizes varied among studies. Therefore, their results should not be compared without considering that there might be differences due to the different equipment deployed.

The use of diving has also proved to be a popular method to sample benthic marine debris, at least to a few tens of metres. Snorkeling, scuba diving and manta tow were used in 41.3% of the studies. The important features of these methods are that they can be used in all types of bottoms (including reefs), the debris are observed *in situ* so even small items can be counted, and the debris can be sampled without disturbing the environment. The limits are that only small areas can be sampled at a time and that their use is restricted to shallow depths. Another specific

issue related to manta tow surveys is due to their relative speed such that items with less than 40 cm diameter are difficult to observe. However, diving has been applied to study the distribution and quantification of benthic marine debris only in the last seven years, so this is a method that could be more explored in future.

Submersibles and sonar are not common methods to study benthic marine debris, mainly because of their high costs of operation. Both methods are indirect, that is, the debris can be seen, but they are not collected or closely inspected. Because of this, the debris cannot be classified into different categories. The problem is even greater for sonar, since it only shows the outlines of the objects and thus has a high chance of incorrectly identifying benthic marine debris.

In the Florida Keys National Sanctuary and Northwestern Hawaiian Island, the main concern was about lost fishing gear, which could affect organisms, such as the endangered Hawaiian monk seal (*Monachus schauinslandi*) (Donohue et al., 2001; Boland and Donohue, 2003). Interest in evaluating benthic marine debris in these protected areas is relatively new (Donohue et al., 2001). There are also a great number of studies that quantified benthic marine debris in the Mediterranean. This basin has been vastly studied and the first evaluations of benthic marine debris there (Bingel et al., 1987; Galgani et al., 1995a,b; Galil et al., 1995) were a part of another project, that is, they were a consequence of continuous observations of debris caught in the nets used in studies of fish stocks, for example.

Studies of benthic marine debris are focused in a few regions of the world's ocean, normally areas where shipping lines and recreational tourist activities are concentrated. This explains why most studies point out the origin of the debris as being from marine activities. The studies that attributed land as being the source of the debris were conducted near the shore (Nagelkerken et al., 2001; Acha et al., 2003) or in enclosed environments that accumulate more easily the debris that comes from rivers (Stefatos et al., 1999; Galgani et al., 2000).

One of the major problems encountered when analyzing the published studies was that not all of them presented the minimum and maximum depth of the region sampled, and half of them did not state the total area sampled. This information is needed.

The lack of uniformity in the units of density is also a major problem when comparing results of different studies. Even though transformations of unit can be made in some cases, this might lead to errors. The choice of unit to quantify the debris (number of items, weight) is also very important, as the variance of the material may introduce distortion to the results (Galil et al., 1995).

The number of categories into which debris were classified depended on the studies which focused on lost fishing gear and depended also on the methods used.

Studies of lost fishing gear have gained more importance over the years. The first article published in this context was in 1999, by Hess and co-workers who studied fishing-related items around Kodiak, Alaska. Since 2000, eight other articles (Stevens et al., 2000; Donohue et al., 2001; Chiappone et al., 2002, 2004, 2005; Revill and Dunlin, 2003; Boland and Donohue, 2003; Dameron et al., 2007) focused on this theme, of a total of 16 studies about benthic marine debris. Of these eight articles, six were done in the protected areas of Florida Keys National Sanctuary and Northwestern Hawaiian Island, which demonstrate the concern of the impacts these items can cause in these environments. Another important reason for evaluating the distribution of lost fishing gear is the economic impact they can have on the fisheries industry, because this fishing gear may continue to fish without human control (ghost fishing).

June (1990) proposed the development of a standardized data collection protocol, data base system, analysis methodology and reporting format. The only manual about specific methods to survey benthic marine debris was published 15 years ago (Ribic et al., 1992). During the last decades many changes have occurred, based on new technologies and information, so there is a need for a revision of this manual. Standard methods and units used to quantify the debris are needed for comparisons of the results between different areas of the world.

Basic standard requirements to any benthic marine debris study would be related to both the information collected and its reporting format. In order to promote better environmental conservation, it would be necessary to know the type (within use or source categories), number, composition, and size of each item recorded. The reporting units must express principally density (items/unit of area). Also, minimum and maximum depth of each sampled region (or sample) needs to be reported, together with the total sampled area of the study.

When each method permits, other interesting information to be added to the basic requirements listed above would be: mass (weight/area); distance from the shore; interaction with the environment (e.g. contact with the biota, buried/trapped or free) and; potential risk to human activities (e.g. bathing, boating, fisheries).

There are differences in the sampling methods, but this does not compromise the comparison of the results. Many benthic marine debris sampling methods are complementary, and can be deployed along a depth/environmental gradient. Provided the minimum requirements are fulfilled, even being of very different nature, methods will allow comparisons among different environments and habitats of the sea floor.

The magnitude of the benthic marine debris problem already requires specific experimental designs in order to produce a realistic picture of its present status. The studies of benthic marine debris need to be expanded to wider regions of the world's oceans assessing depth/environmental gradients as a strategy to detect its main sources and patterns. Only then proper managerial actions could be taken to solve or, at least, help mitigate this problem.

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